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TRANSIT COOPERATIVE RESEARCH PROGRAM

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TCRP Report 48

Integrated Urban Models for Simulation of Transit and Land Use Policies: Guidelines for Implementation and Use

Transportation Research Board
National Research Council

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Integrated Urban Models for Simulation of Transit and Land Use Policies: Guidelines for Implementation and Use

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The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), *Transportation 2000,* also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA; the National Academy of Sciences, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

These Guidelines describe how transit agencies, metropolitan planning organizations, and state DOTs can act today to initiate or expand their analytical tools for integrated land use-transportation planning. The Guidelines are intended for the general reader having an interest in the effects of transit on land use. The Guidelines describe currently available integrated models, the characteristics of an "ideal" integrated model, and steps that a planning organization should take in order to support and expand such modeling capability. A more detailed Final Report is available for the practitioner on the TCRP website.

Although federal transportation policy, as reflected in the Intermodal Surface Transportation Efficiency Act of 1991 and the Transportation Equity Act for the 21st Century, places a high priority on considering land use in transportation planning, currently available models do not adequately simulate the effects of major transit investments on land use. The U.S. DOT, in conjunction with other federal agencies, undertook the Travel Model Improvement Program (TMIP) to improve the modeling capabilities of the transportation industry, but supporting research is still needed to ensure that the next generation of travel demand models simulates land use and transportation interactions more accurately, and, specifically, the effect of public transit access on land use.

The objectives of TCRP Project H-12 were to define the effect of transit access on land use, evaluate the transit access component of current land use models, and augment the ongoing work of the U.S. DOT in the TMIP. In accomplishing these objectives, the University of Toronto, in association with DELCAN Corporation, developed the characteristics of an ideal integrated model and then reviewed six integrated land use-transportation models against the features of the ideal. The authors estimate that there may be more than 20 such models available in the world of varying degrees of completeness and integration. The six chosen for review were selected because they are operational in a practical setting and include explicit treatment of prices in the land-development component of the model.

These Guidelines summarize the attributes of an "ideal" integrated model and describe how an agency should proceed step by step to build its own integrated modeling capabilities. Six levels of modeling capability are described with a checklist of input and analytical requirements for each level. The Guidelines stress that, to expand capability, a plan is essential and that an incremental approach is most likely to be successful. Data collection is the first step. A good travel demand modeling capability is necessary before an agency should consider advancing to integrated models. A national research and development program for improving integrated land use and transportation models is outlined.

The more detailed Final Report for this project is available on the TCRP website as Web Document 9 (www4.nas.edu/trb/crp.nsf). The Final Report contains a discussion of the relationship between public transportation and land use, a review of the six integrated transportation and land use models, and a review of how each model handles public transit. There is an extensive bibliography, and Appendix B describes the logic and equations for a logit-based land allocation model with endogenous price signals.

In early 1999, the National Cooperative Highway Research Program published a related product—*NCHRP Report 423A*, "Land Use Impacts of Transportation: A Guidebook." This document reviews a range of quantitative and qualitative tools available to analyze land use-transportation issues, describes case studies of applications, and includes a review of land use models. The report also describes the behavioral framework motivating key actors (e.g., households, developers, and local governments) on the urban scene, and concludes with step-by-step guidelines for conducting land use analysis. An integrated land use model, UrbanSim, will be available by mid 1999. More information on the UrbanSim model can be obtained on the Internet at http://urbansim.org. The NCHRP report may be ordered at the same address as TCRP products (see preceding page).

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INTEGRATED URBAN MODELS FOR SIMULATION OF TRANSIT AND LAND USE POLICIES: GUIDELINES FOR IMPLEMENTATION AND USE

SECTION 1

INTRODUCTION

1.1 PURPOSE

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) required metropolitan and statewide transportation plans to be integrated with land use plans. The Transportation Equity Act for the 21st Century (TEA-21), the 1998 successor to ISTEA, also recognizes the need for consistency in transportation and land-use plans, albeit in somewhat broader language. However, both ISTEA and TEA-21 leave the means of achieving this consistency to individual metropolitan planning organizations (MPOs) and state DOTs.

Land use and transportation are related. That land use and transportation affect air quality is well established, both practically and legally. It follows that the attainment of air quality standards depends not only on travel demand and the transportation system that meets that demand but—more fundamentally—on urban form and the distribution of population and employment. However, these relationships are not fully understood, despite considerable research and study in recent years.

A concentrated research effort to develop new analytical models that can simulate and forecast the land use-transportation-air quality chain is being made. Previously, the primary focus has been on the relationship between transportation and air quality.

The ability to model the land use-transportation relationship remains somewhat limited. Some aspects of this relationship are relatively well defined—notably, site- or neighborhood-specific trip generation rates for different land uses—but these represent microscale relationships. Macroscale (i.e., regionwide) relationships are much less well defined; however, the ability to analyze the regionwide effects of a particular land use scenario, urban form, or transportation policy is essential to the success of, for example, an air quality improvement program. The most efficient, comprehensive, and promising way of analyzing regionwide relationships is through integrated land use and transportation models. Thus, a need was identified to advance the state of the art in integrated models.

To address this need, TCRP Project H-12 specifies the ideal, next-generation integrated land use-transportation model, as well as a 5-year research program for its development. This volume, *Guidelines for Implementation and Use,* describes how MPOs, state DOTs, and other planning agencies can act today, to initiate or build on existing integrated land use and transportation analytical tools (models). (Note: These guidelines emphasize integrated land use and transit modeling, where transit planning can be taken as a specific case of transportation planning in general.)

This document is intended to stand alone and has been structured to enable readers to answer the following key questions:

- Why should I use an integrated land use-transportation model?
- Is it better than what I am doing now?

- Is it any good?
- Is it useful?
- Is it valid?
- Is it practical to use?

The specification for the model is described in detail in the Final Report (Miller, Kriger, and Hunt, 1998).

1.2 AUDIENCE

Although these guidelines focus on land use-transportation modeling, they will be of interest to anyone involved in land use-transportation planning. Specifically, the guidelines will be of interest to planners, engineers, analysts, researchers, and decision-makers in the following:

- MPOs,
- State DOTs,
- Municipal and local governments,
- Transit operators,
- Land developers,
- Consultants, and
- Academia.

1.3 HOW THESE GUIDELINES SUPPORT INTEGRATED PLANNING

The *Guidelines for Implementation and Use of Integrated Land Use-Transportation Models* describe computerized mathematical models that can be used for transportation and land use planning as well as the data that drive these models. The models and data are used to analyze and forecast the implications of alternate transportation plans and land use scenarios.

Many different types of models are used in planning. Perhaps best known are travel demand forecasting models, which have been de facto requirements for urban transportation planning for several decades. The main outputs of these models are projections of traffic or ridership throughout a transportation network or on a particular facility. Land use models also are used in planning, primarily to project and distribute population and jobs within an area.

Although transportation and land use are intricately related, traditionally, neither the planning for the two nor the available planning tools have been well integrated. *Integrated* land use-transportation models do exist. Such models combine travel demand forecasting functions with land use forecasting functions and recognize that the distribution of population and jobs depends, in part, on transportation accessibility. The reverse also is true. Thus, in addition to *simulating* the land use-transportation interaction, integrated models incorporate feedback from the forecasting processes.

There are relatively few such integrated models in the United States because of the following:

- The complexity of the integrated modeling process, as an operational tool;
- Theoretical problems of completeness and consistency (especially with regard to simulating the role of markets and pricing in the decisions of households and firms); and
- The comprehensiveness of the data required.

More commonly, land use models are used to project demographic and socioeconomic inputs to travel demand models. In this application, a feedback mechanism does not formally exist. The land use-transportation interaction can be examined only through the creation of alternate scenarios (i.e., by revising the set of land use inputs to the travel demand model, according to the results of a previous run of the travel demand model, other analysis, or some other combination of computerized/manual interventions). As a result, pricing and other decisions tend not to be modelled at all; often they are only implied in the development of the various alternate scenarios.

These guidelines were prepared as part of TCRP Project H-12, which focused on specifying the ideal, next-generation integrated land use-transportation models. The next generation of integrated models probably will require a 5-year research and development effort. In the interim, these guidelines are intended to assist MPOs, state DOTs, and other practitioners in two ways:

- By improving the current practice of integrated land use-transportation modeling (by outlining methods and techniques that can be applied today using existing models and data) and
- By providing a starting point for the long-term development of the next generation of integrated models.

1.4 ORGANIZATION

The guidelines are structured in the following way:

- The case for integrated models is summarized in Chapter 2.
- The land use-transit relationship and its implications for integrated models are discussed in Chapter 3.
- The current and future state of the art in integrated models is summarized in Chapter 4.
- Chapter 5 outlines a two-part approach to achieving the future state of the art. The approach is evolutionary (i.e., building on and expanding on existing capabilities and data) and research-based, in which an entirely new set of integrated models is proposed under focused research and development.
- Chapter 6 reviews how planning agencies can begin to implement or upgrade their own capabilities.
- Appendix A provides an overview of the legal context for integrated planning.
- Appendix B provides a glossary of selected modeling terms used in these guidelines.

SECTION 2

THE CASE FOR INTEGRATED MODELS

Recently, interest in integrated models has grown. The five key reasons for this renewed interest are described in the following sections.

2.1 LEGAL REQUIREMENTS FOR IMPROVED INTEGRATION

ISTEA and the Clean Air Act Amendments of 1990 resulted in fundamental changes to the planning and funding of metropolitan and state transportation facilities and services. In particular, ISTEA specified that transportation plans must take into account the "likely effect of transportation policy decisions on land use and development and the consistency of transportation plans and programs" with land use and development plans. TEA-21, ISTEA's successor, recognizes the land use-transportation relationship, although this is considered in the broader context of economic developmental, environmental and "quality of life" issues. Both ISTEA and TEA-21 require transportation plans to conform with CAAA requirements, thereby linking land use, transportation, and air quality.

However, neither ISTEA nor TEA-21 specifies how the land use-transportation integration is to be achieved. TEA-21 does specify that "mass transportation supportive existing land use policies and future patterns, and the cost of urban sprawl" be considered explicitly in the decision-making (justification) for a "new fixed guideway (transit) system or extension of an existing fixed guideway system."

Appendix A provides more details on how ISTEA, TEA-21, and CAAA address integrated land use-transportation planning.

2.2 FUNDAMENTAL REDEFINITION OF TRAVEL MODELING CAPABILITIES

The Travel Model Improvement Program (TMIP) was established by the U.S. DOT and the U.S. Environmental Protection Agency (EPA) in 1993. The program constitutes the most fundamental restructuring of transportation modeling in several decades. TMIP is driven in part by the legal need for improved methods to address the transportation-air quality relationship and by the recognition that the traditional transportation modeling algorithms are not sufficiently responsive to current transportation issues. These needs coalesced with advancements in our understanding of travel behavior (e.g., in random utility-based models, activity-based models, advanced econometric methods for model estimation, and microsimulation). Finally, TMIP takes into account significant improvements in computing, including hardware and software and, especially, data and data management capabilities (notably, geographic information systems [GIS]).

A key TMIP product is a new prototype travel demand model (TRANSIMS), which is now under development. This is the focus of one of six TMIP "tracks." One track ("E") is devoted to ways of improving modelling capabilities and data for analyzing the land use-transportation interaction, in the context of the overall TMIP improvements to travel demand forecasting. Whereas the other TMIP tracks could be described as focusing on the transportation-air quality relationship, Track "E" looks at the land use-transportation part of the chain. Although not funded directly under TMIP, this study relates directly to the objectives of Track "E."

A useful overview of TMIP is provided in Weiner and Ducca (1996).

2.3 INTERDEPENDENCE OF LAND USE AND TRANSPORTATION POLICIES

There is growing recognition that the land use-transportation interaction is significant and must be understood, analyzed, and accounted for in order to ensure that land use and transportation plans and policies are effective and can succeed. Most important, there is a growing appreciation of the idea that transportation and land use policies cannot succeed independently of one another.

Some analysts argue that a significant land use-transportation interaction does not exist: given the near-ubiquity of the transportation (road) network, the ability to influence land use decisions with transportation investment is minimal, at best. Also, the choice of residential and firm locations depends on many factors, of which transportation accessibility is only a minor one.

We perceive the interconnections between points (activities) in space through the medium of the transportation system. Build the transportation system differently, and people will use it differently, and they will organize themselves over space differently. Build the city differently, and the transportation "needs" will be different. Any apparent "lack of relationship" simply reflects one (current) land use-transportation combination in which near-ubiquitous automobile-based mobility has "loosened the bonds." It does not mean that other options and outcomes are not possible; nor does it mean that we do not need to explore and analyze how the overall urban system (transportation and land use) will evolve over time if we are to understand how best to invest in our transportation system.

Achieving a better understanding (and, eventually, representation) of the land use-transportation interaction is essential to the urban transportation policy debate in the United States (and, for that matter, elsewhere), whether the discussion is about roads, transit, or non-motorized modes of travel.

One of the most important examples is whether constructing a new urban expressway has a net beneficial effect (because of congestion relief and associated increases in average travel speeds) or a net negative effect (because of increased induced sprawl of land use and travel patterns, increased auto dependency, and so forth). A recent "blue ribbon" panel in the United States came to no definitive conclusion on this issue (CSIHCIAQEC, 1995), while a similar study in the United Kingdom endorsed the negative effect case (SACTRA, 1994). That considered professional opinion differs so dramatically and that so much of the debate over such issues reflects subjective arguments (often with strong ideological overtones) point to the failure of current analysis methods to provide definitive insight into such problems.

Another important example concerns road pricing. Increased privatization of roads (and, outside North America, of transit) coupled with the growing need to offset transportation costs (including pollution) with new revenue sources has led to the need for better tools to forecast traveller behavior when out-of-pocket costs as well as travel times are changed. Traditional travel demand forecasting models are commonly used to forecast both volumes and revenues on new facilities. Improved data, obtained through such techniques as stated preference surveys, have permitted significant improvements to be made to behavioral choice models. However, a somewhat closed system generally is modeled: a redistribution of home-work trips, for example, that is projected as a result of new road tolls may be *indicative* of an effect but cannot be considered representative if effects on land use are not considered in the model. There is also little or no ability to consider the effect of road pricing on, for example, auto ownership. Moreover, the introduction of a road toll in reality may be seen simply as the cost of living or of doing business in a particular city, with a corresponding increase in wages to compensate—and no real change in travel behavior. Concern is real and growing—in no small part because banks and other investors in privatized facilities have begun to question why some travel and revenue forecasts seem overly optimistic.

2.4 EFFECTIVENESS OF TRANSIT INVESTMENTS AS ALTERNATIVES TO NEW ROADS

A key element of ISTEA (and TEA-21) funding provisions was the promotion of alternatives to the automobile, as a means of attaining air quality standards and as part of a more holistic treatment of mobility needs (i.e., moving people and goods and not just vehicles).

Transit can be an attractive alternative to the private automobile. However, accuracy of ridership forecasts is a long-standing issue. A 1989 UMTA report questioned the veracity of rail transit ridership forecasts (Pickrell, 1989). The report recommended that forecasting procedures should be improved by bringing the forecasting horizon closer to the present (i.e., shorter term rather than long term), by developing procedures to isolate and examine cause-effect determinants (of ridership), by conducting sensitivity analyses for validating forecasting models and for assessing the effects of different assumptions, and by comparing forecasts with observed conditions elsewhere.

The report, which generated considerable comment in the transportation community, is mentioned here, in part because TMIP aims to address some of the stated concerns (e.g., improving the accuracy of forecasts). More important to this project, however, the accuracy of transit ridership forecasts depends in part on the simulation of land use changes and new development that may result from a new transit line (and vice versa). Therefore, it is an important consideration for short- and long-term directions for integrated modeling.

2.5 ROLE OF ECONOMIC DECISIONS, MARKETS, AND PRICING

Economic decisions affect the land use-transportation relationship. Some decisions are short term, while others are of much longer duration. An example of the former is the driver's route choice in the face of changing traffic conditions. Examples of the latter are the decisions, first, to form a household (or firm) and, second, where to locate that household (or firm). In between may be decisions concerning whether to acquire an automobile (or a second automobile), which job to take, and so forth. These can be described as demand-side economic decisions (i.e., decisions made by those who use the land use [development] and transportation systems).

Supply-side economic decisions also affect land use and transportation. Such decisions include that of a developer choosing to build on a piece of land (as well as the decision of what to build, in what quantity, at what price, and so forth). The supplier of transportation infrastructure and services (whether a state DOT or a private carrier) behaves similarly.

Many of these are both demand- and supply-side decisions. Regardless, economic decisions, pricing, and markets are fundamental to land use and travel decisions and investments and, therefore, must be considered in integrated land use-transportation plans. However, these are not well considered in existing models and capabilities.

SECTION 3

THE LAND USE-TRANSIT RELATIONSHIP

3.1 A TAXONOMY

What is the effect of a new transit line on land use? How do changes in land use affect the demand for transit? How much and what type of development would be attracted to the transit corridor as a result of the new facility? How much of the projected ridership on a new rapid transit line depends on new development that would be attracted by the line? How much ridership would be diverted from existing transit services? These questions constitute the primary practical motivation behind the current project.

The relationship between transit and land use can be described in several ways. A useful starting point is a description of responses to the introduction of a new transportation facility. Table 1 provides one such description or taxonomy. With such a taxonomy, it is possible to begin to define and quantify the various relationships.

Table 1 is adapted from Stopher (1991, as cited in Weiner, 1997), who developed a taxonomy of eight possible travel responses to an increase in road/highway capacity.[1] The taxonomy could be adapted to transit, as well. Table 1 compares the eight travel responses to an increase in road/highway capacity (after Stopher, 1991) with analogous responses to an improvement in transit service. The transit improvement of interest is an increase in the transit level of service that would result from a new fixed guideway or an extension to an existing guideway (i.e., a capital improvement).

The table shows that all eight possible responses apply to both the road and transit improvements. However, responses may differ, in quality and extent. For example, the responses to the road/highway improvement are driven largely by changes in congestion; whereas responses to the transit improvement are defined more in terms of accessibility and convenience. Notwithstanding, as Section 3.2 describes, the land use-transit relationship is complex and varied.

Section 3.2 also addresses a supply-side response to new transportation facilities, namely, the development of land. In both the road and transit improvements, all eight responses listed in Table 1 relate only to the demand for transportation. Only the last response—new development—has a direct supply-side response—the development of land.

3.2 DEFINING THE LAND USE-TRANSIT RELATIONSHIP

The literature documenting the current empirical understanding of the relationship between land use and transit is extensive. The results of a review of this literature (Miller et al., 1998) are summarized below, from two perspectives: first, the implications of land use (defined as urban form) on travel; then, the implications of travel on urban form.

3.2.1 Implications of Urban Form on Transit Travel

The literature can be categorized in terms of seven factors that influence travel activity. The influence of each of these factors on transit travel is summarized below, along with its implications for integrated models:

1. **Residential Density.** Higher residential densities are seen as an important means of achieving urban "efficiency" or "sustainability"; the idea being that high-density, mixed-use development provides more opportunities for travellers to leave their automobiles at home (because activities are closer together and higher densities make transit services economically feasible). However, the empirical evidence is very mixed.

   Implications for Integrated Models. The role of density as a direct explanatory variable with respect to transit use, automobile vehicle-miles of travel (VMT), and so forth, typically declines significantly when "other factors" (e.g., socioeconomic characteristics of the trip makers, accessibility by mode to destinations, and automobile availability) are considered. These other factors are discussed below.

2. **Transit Supply.** Relatively few studies explicitly include measures of transit supply in their analyses of urban form impacts, presumably because of data limitations. When such variables are included in the analy-

[1] Stopher's original taxonomy, and Weiner's reference, refer to the 1989 legal challenge of the San Francisco Metropolitan Transportation Commission's proposed transportation plan. The challenge explicitly considered existing capabilities to integrate land use-transportation models and influenced the development of ISTEA.

TABLE 1 A comparison of travel responses to road and to transit improvements

Travel Response*	Travel Response to Road/Highway Capacity Increase*	Travel Response to Transit Service Increase
Foregone Trips	Reduction of congestion through new capacity relieves pent-up demand, thereby increasing travel.	New capacity/services relieves pent-up demand *if* no other travel alternatives exist.
Peak Spreading	New capacity reduces need to delay/advance trips to the peak shoulder, thereby increasing peak travel and peak congestion.	New capacity/service reduces need to delay/advance trips to peak shoulder, thereby increasing peak ridership and crowding.
Route Changes	New capacity draws trips from parallel, more congested routes, thereby increasing corridor travel.	New capacity/service draws trips from parallel, less attractive transit routes, thereby increasing ridership on the facility (but not on the overall transit system).
Chained Trips	Reduction of congestion makes it more convenient for travellers to split trips ("out-and-back") rather than chaining trips; thereby increasing travel.	Chained trips may be split if destinations are more conveniently accessed by the new transit capacity/service, thereby increasing ridership.
Destination Changes	Reduction of congestion increases attraction of "further-way, more-desired" locations, thereby increasing travel.	Improvement in capacity/service increases attraction of "further-way, more-desired" locations, thereby increasing ridership.
Mode Changes	Transit users and ridesharers find it more convenient to return to driving, due to reduction in congestion; thereby increasing travel.	New capacity/service attracts non-users to transit, thereby increasing ridership.
Automobile Ownership	If automobile use increases (due to mode changes), automobile ownership will increase.	Improvement in capacity/service may, at best, postpone the need for the purchase of a new automobile but only for those who benefit directly and whose lifestyle, proximity to the transit system, and so forth, do not require the use of an auto.
New Development	Long-term maintenance of reduced congestion levels will increase and/or change development patterns in the vicinity of the facility and will redistribute households and jobs.	Long-term transit 'commitment' will increase and/or change development patterns in the vicinity of the facility and will redistribute households and jobs.

*Adapted from Stopher, P., *Deficiencies in Travel Forceasting Procedures Relative to the 1990 Clean Air Act Amendment Requirements*, presented at the Annual Transportation Research board meeting, Washington, DC. January 1991. As cited by Weiner, E., in *Urban Transportation Planning in the United States, An Historical Overview*, US Department of Transportation, fifth edition. September 1997, p. 195 (Table 9).

sis, they often are found to play a significant role in explaining modal choices, VMT levels, and so forth and to reduce the explanatory power of density measures within the analysis (PBQD, 1996). This reflects the classic demand-supply relationship that exists between factors such as residential density and transit service levels (i.e., the better the transit service, the more people will use it; the more people potentially available to use a given service, the higher the level of service that can be provided cost-effectively).

Implications for Integrated Models. The evidence suggests that transit use increases significantly once certain density thresholds are exceeded. However, this is also a function of the transit supply. Both demand (as represented by corridor density) and supply (as measured by the supply of transit service) processes must be considered.

3. **Automobile Ownership.** One quite consistent finding is that households in higher density neighborhoods tend to own fewer vehicles and that households owning fewer cars then tend to use transit more and generate fewer VMT.

Implications for Integrated Models. The role of automobile ownership within the overall land use-transportation interaction is often overlooked. In other words, automobile ownership is often treated exogenously to the interaction. This may reflect the assumption that automobile ownership in many areas of the United States is so high and so pervasive that it ceases to be an interesting explanatory (or policy) variable. It may also result from the view that automobile ownership is just one more socioeconomic descriptor of trip makers, determined largely exogenously to the travel decision-making process.

However, these assumptions significantly underestimate the extent to which automobile ownership decisions are integral to the land use-transportation interaction. In particular, automobile ownership is a critical "intermediate link" between household location choices (e.g., where to live and where to work) and their subsequent activity/travel decisions. Households whose members live and/or work in low-density suburban areas will of necessity (if not also preference) be automobile-oriented, tend to have a high automobile ownership level, and make most (if not all) trips of any significant distance by automobile. Households whose members live and/or work in denser, transit-oriented communities (where the transit orientation arises from the transit-land use interaction discussed above) may opt to own fewer cars (e.g., only one instead of two or more). Once a household decides to own, for example, one less car, by necessity it is committed to driving less and using other modes of travel (e.g., transit and walking) more, if it is going to maintain a comparable level of activity, relative to a household which owns that "extra" car. Thus, as in the transit service case previously discussed, a proper specification of the urban form-travel demand interaction requires including automobile ownership as an endogenous component of the system.

Many policy issues of current relevance (from carbon taxes to vehicle technology options) have direct or indirect impacts on vehicle ownership decision-making.

4. **Socioeconomics**. Socioeconomic factors (e.g., income, age, gender, and occupation) (in addition to automobile ownership) affect travel behavior significantly. People's travel needs and capabilities vary dramatically as as result of such factors. This is why most current travel demand modeling methods (e.g., random utility models and activity-based models) are developed at the disaggregate level of the individual trip maker in order to properly capture the diversity of behavioral responses that occur among different types of people.

   Implications for Integrated Models. As with the factors discussed above, it is the interaction between socioeconomics and urban form that is central to the understanding and modeling of people's locational and activity/travel decision-making. Different people will respond to different density levels/urban designs in different ways. It is, therefore, not a question of "which is more important"—density or socioeconomics—in explaining behavior, but a question of understanding how behavioral responses to changes in density and so forth will vary by socioeconomic characteristics.

   Given the importance of socioeconomic factors, they must be explicitly represented within the modeling systems, and these models must be sufficiently disaggregated to properly capture their effects. This suggests the need to include *within* model systems explicit representations of demographic and economic processes. A strong case can be made that one of the reasons why many advanced disaggregate modeling methods have not yet achieved widespread adoption within operational planning contexts is their inability to predict credibly the detailed socioeconomic attributes which they require.

5. **Employment Density**. The effects of employment density have not been investigated to the same extent as have those of residential density. The reported findings, however, are quite consistent: increased employment concentrations significantly affect transit use, walking (where feasible), and ride-sharing. These results tend to hold for central business districts (CBDs), suburban employment centers, and employment centers near commuter rail stations. This clear result relative to the more ambiguous residential density case probably reflects the more direct relationship that almost certainly exists between employment density and transit service supply (i.e., such centers are readily identifiable foci for transit services). Also important are the "levels of service" for other modes (e.g., higher employment densities increase the chances of ride-share "matches" and higher density areas, particularly in CBDs, tend to have higher parking costs and/or walk times from parking).

   Implications for Integrated Models. These findings reinforce the importance of the employment/activity center trip end in modeling. There is a strong tendency in both theory and practice to focus on the residential side of the land use problem. The spatial distribution of employment (and, more generally, out-of-home activities, both work- and non-work-related), however, may well be a much stronger "driver" of travel behavior *and* transportation supply options. This aspect of land use also may be more susceptible to successful planning control.

6. **Accessibility**. The term accessibility is used here simply to mean a variety of measures of "how well connected" a given location is with activities of a given type (e.g., work opportunities and shopping destinations). Usually, accessibility is expressed in terms of *how much* of a given activity is *how close* to the location in question. Thus, for example, one can speak of the accessibility of a residential zone to employment opportunities.

   The issue concerns *how* important accessibility is relative to other factors, not *whether* it is important. Conceptually, accessibility—and the notion of connectivity—is central to transportation planning. This explains why, in the literature, the effect of factors such as residential density or neighborhood design appears to be mixed: it tends to ignore the critical question of *connectivity* (e.g., it is of little use having a dense neighborhood that does not have good access to relevant activity destinations; transit requires travel corridors of reasonable density, consisting of both "production" and "attraction" points to be most effective;

walking requires proximity between origins *and* destinations). This is not to say that, in areas possessing very high degrees of connectivity and so forth, accessibility may be so universally high that it may not seem to matter; this simply represents one extreme point on the continuum of possible situations.

Implications for Integrated Models. Linking origins with destinations to create flows is the fundamental task of travel demand models. Understanding how urban form combines with the transportation system to provide accessibility to activities *and* choices is central to this travel demand forecasting process. To address this issue comprehensively requires an integrated approach to the modeling of location choice and travel behavior.

7. **Neighborhood Design.** In the last few years, much attention has been given to the role of local neighborhood design in determining travel behavior. In particular, advocates of neo-traditional neighborhoods and town planning have argued that such neighborhoods should encourage more walk and transit trips, shorter trips, and so forth, thereby contributing to reductions in automobile VMT, emissions, and so forth.

   Here, again, the literature is mixed in its findings, although in part this may reflect a lack of available analyses and so forth. However, the relevant point here is that people's "activity time-space prisms" extend well beyond the local neighborhood, given both the levels of accessibility available to many people and their expectations/needs concerning their participation in activities of various types. Jobs-housing balances, for example, are virtually impossible to achieve in practice, given the nature and dynamics of our complex labor markets. Similarly, the desire for the widest possible range of consumer goods, experiences, and so forth, means that the "action spaces" will inevitably extend well beyond the neighborhood boundary.[2]

   Implications for Integrated Models. The approach of this study is "top-down," since we are looking at a region in its entirety. However, much of the integrated land use-transportation (transit) planning that is done in the "real world" is at the neighborhood level. The preceding discussion—while not intended to be a comprehensive discussion of neighborhood planning—is meant to highlight the need for a comprehensive, integrated view of neighborhood design within the overall land use-transportation interaction. This is essential to understanding the interactions involved and then to generate useful analyses and forecasts on the basis of this understanding.

Figure 1 conceptually links these seven urban form factors with travel activity. (The figure also recognizes the explicit role of transportation supply in travel activity (i.e., the definition of the road and transit systems). In this figure, activity/travel behavior is shown to be the "outcome" of a complex set of interactions among the various factors discussed above.

Figure 1 illustrates two key points:

1. "Urban form" or "land use" or "physical design" (as represented by residential density, employment density, and neighborhood design) provides a *context* for human behavior, which, in this case, includes location decisions (e.g., residence and job locations), automobile ownership decisions, and, ultimately, activity/travel decisions. Increased residential density does not directly "cause" reductions in automobile VMT. Rather, under the right circumstances, it may attract a resident population with particular socioeconomic characteristics and desired activity patterns who will make automobile ownership and travel decisions that will result in increased transit/walk use, reduced VMT, and so forth relative to what they might do in other urban form contexts.
2. Numerous supply-demand or feedback interactions exist within this system. Travel decisions affect road congestion levels, which, in turn, affect travel decisions; residential densities combined with attributes of the resident population affect the level of transit service provided, which, in turn, affects the attractiveness of the residential area for people of different types; and so forth. Ignoring these complex interactions and analyzing the system in a partial, overly simplified way almost inevitably leads to misleading or even erroneous results.

3.2.2 Implications of Transit on Urban Form

To this point, the discussion has centered on how urban form affects travel behavior; however, transit systems also affect urban form. There is a diversity of findings on the effects of light rail, subway and commuter rail lines and stations on residential density, employment density, property values, and so forth. Four main observations may be made, all of which have implications for integrated urban modeling:

1. **Fixed, Permanent Transit Systems Have the Most Significant Effect**. No mention of the land use effects of shared-right-of-way bus systems, HOV systems, and so forth is made. This reflects a widely held belief

[2] This is not to say that the details of neighborhood design are unimportant. It is such design details, after all, that determine the residential and employment densities within the neighborhood, the ease and attractiveness of walking, and the ease and efficiency of providing transit services within the neighborhood, to name just a few important issues.

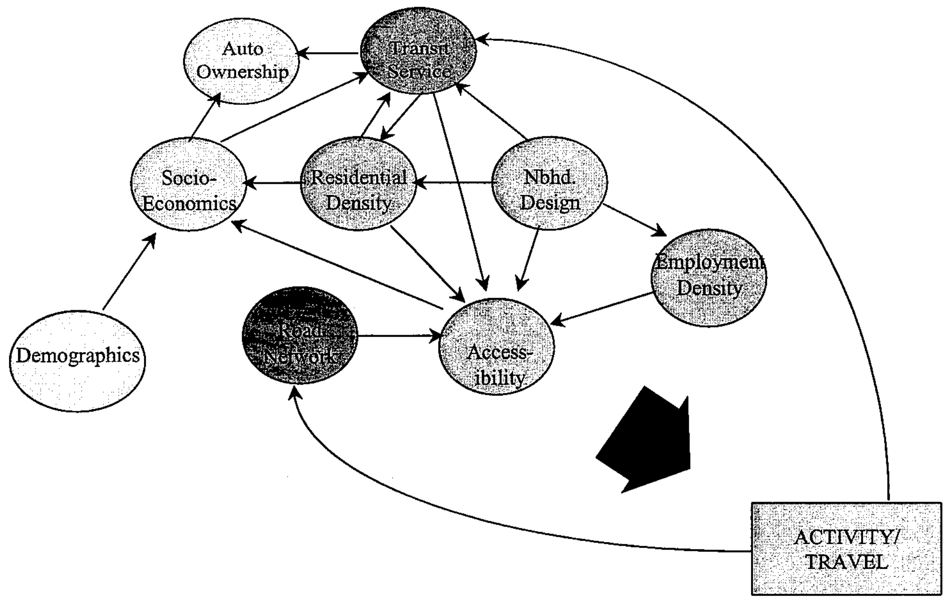

Figure 1. Urban form impacts on activity and travel.

that only major fixed guideway infrastructure can have a discernable effect on urban form development. Bus routes can change monthly; HOV lanes can generally be converted to general traffic use with minimal effort. Further, such systems (especially bus systems) tend to be ubiquitous, providing a base background service over an extended area. Such flexible, relatively ubiquitous systems can provide reasonably high levels of accessibility, which, in turn, influence location and travel choices, but which, in and of themselves, are assumed to be unlikely to stimulate major land development decisions.

2. **Transit's Effects Are Measurable Only in the Long Term**. Urban form evolves on a time scale of decades. Short-term effects are inevitably negligible and short-term responses are not necessarily indicative of long-term effects. Practical difficulties exist, however, in long-term empirical studies. In addition, many factors change over the long term, making unambiguous determination of the effect of the transit system difficult, if not impossible.
3. **Transit's Effects on Land and Development Markets—Not Land Values—Must Be Considered.** Most of the empirical evidence relates to the effects of transportation on land values. However, land development, building stock supply, and residential and commercial location decisions all occur within economic *markets*, within which supply-demand processes (for land, buildings, and so forth) exist and are reconciled through the determination of market-clearing prices.
4. **Transportation Facilitates Development But Does Not Cause Development**. In particular, rail transit is a "necessary but not sufficient condition" for development to occur. Although now more than 20 years old, the work of Knight and Trygg remains the most comprehensive and definitive study of this issue to this day. In their 1977 study, they build a compelling case that transit investment is but "one piece of the puzzle" and that local land use policies, other government policies, the local and regional economic climate, and so forth, all must interact in a mutually reinforcing way in order for positive land development effects to occur.

SECTION 4

PRESENT AND FUTURE OF INTEGRATED MODELS

4.1 WHAT INTEGRATED MODELS SHOULD BE ABLE TO DO

Integrated urban models should be

- *Theoretically sound.* In particular, they should be based on the determinants of the land use-transportation connection. Among the key factors to be addressed are the traveler's determinants of mode choice for a particular trip and the developer's determinants of the use of a particular piece of land.
- *Result-driven.* However, they should be respectful of due process and other practicalities (such as the input data that are, or are likely to be, available).
- *Responsive to the issues faced currently by MPOs, transit operators, and other urban transportation planners*—notably, the current fiscal environment, Federal legislation (e.g., TEA-21 and CAAA), the dynamics of local zoning regulations and authorities, the public's desire for accountability in public spending, emerging travel patterns (which may or may not support transit) and the private sector's growing role in supplying public services. Of particular interest is the growing transfer of responsibility to individuals—and, increasingly, their employers—to resolve their own transportation needs with minimal public involvement.
- *Cognizant of the regional, state, national, and global demographic and economic interrelationships* that determine the dynamics of urban form and development.
- *Practical to operate*, with meaningful outputs and a traceable, defensible process.
- *Sufficiently flexible* to accommodate the differing scales and magnitudes of different cities and regions.
- *Presentable* in an understandable way to decision makers and the public.

4.2 THE 'IDEAL' INTEGRATED MODEL: CONCEPT

Figure 2 presents a highly idealized representation of a comprehensive land use-transportation modeling system. The "behavioral core" of this system (the shaded area of Figure 2) consists of four interrelated components:

1. *Land Development.* This models the evolution of the built environment and includes the initial development of previously "vacant" land and the redevelopment over time of existing land uses. This component could also be labelled "building supply," because building stock supply functions (e.g., construction, demolition, and renovation) are included.
2. *Location Choice.* This includes the locational choices of households (for residential dwellings), firms (for commercial locations), and workers (for jobs).
3. *Activity/Travel.* Whether performed by traditional four-stage methods or by emerging activity-based models, this component involves predicting the trip-making behavior of the population, ultimately expressed in terms of origin-destination flows by mode by time of day.
4. *Automobile Ownership.* This component models household automobile ownership levels—an important determinant of household travel behavior.

Points to note concerning these four "behavioral core" components include the following:

- In speaking about land use, transportation planners often blur the distinctions among these four components, especially between the concepts of land development and location choice. A properly specified model, however, must clearly distinguish among these components, which involve very different actors, decision processes, and time frames. These components also permit distinctly different 'degrees of freedom' for the system to respond to exogenous inputs (e.g., construction of new transit infrastructure).
- Each component involves a complex set of submodels. In particular, market-based supply-demand relationships tend to dominate aggregate behavior in each case[3] (e.g., buyers and sellers of houses interact within the housing market and workers and employers interact within the labor market), with prices[4] both being endogenously determined and playing a major role in

[3] With the possible exception of the automobile ownership component, although even here a supply-side clearly exists, even if modelers usually choose not to model it explicitly.

[4] Or, in the case of trip making, travel times.

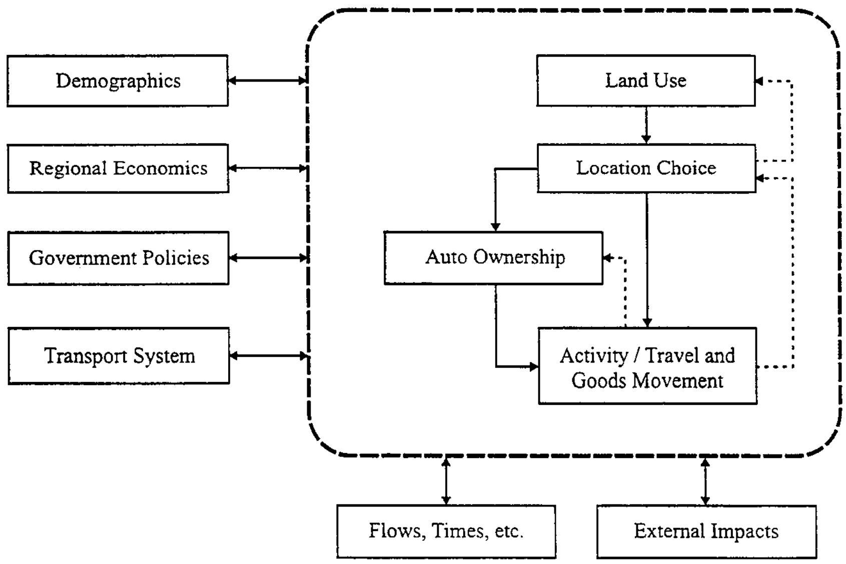

Figure 2. Idealized integrated urban modeling system.

determining the outcome of these supply-demand interactions. Models that ignore these major supply-demand interactions may not capture the dynamic evolution of the urban system over time.

- A simple flowchart, such as Figure 2, never properly captures the temporal complexities of a dynamic system. The vertical hierarchy is chosen to represent short-term conditioning effects (i.e., in the short term, most location choices are made within a "fixed" building stock supply). Similarly, in the short term, most activity/travel decisions are made given a 'fixed' distribution of activity locations (and a fixed number of household autos). In the longer term, all four components evolve, at least partially, in response to feedback from lower levels in the hierarchy (e.g., land use evolves in response to locational needs of households and firms and people relocate their homes and/or jobs at least partially in response to accessibility factors).
- The inclusion of automobile ownership as a separate box within the 'behavioral core' is somewhat unconventional. Automobile ownership is often treated as simply one more (often exogenously determined) input to the travel model. As Ben-Akiva (1974) has observed, however, automobile ownership is an integral part of the "mobility bundle" (which, in terms of Figure 2, Ben-Akiva would define as the combination of the location choice, automobile ownership, and activity/travel components) in that it is fundamentally interconnected with residential location and work trip commuting decision making. This point is strongly reinforced within the empirical literature, in which automobile ownership is consistently found to be an important "intermediate variable" connecting urban form (as measured by residential density and so forth) and travel behavior (as measured by transit use, VMT, and so forth).[5]

As shown in Figure 2, there are at least four major drivers of urban systems:

1. *Demographics:* evolution of the resident population in terms of its age-sex distribution, population size, education level, and so forth;
2. *Regional economics:* evolution of the urban regional economy in terms of its size, industrial distribution, and so forth;
3. *Government policies:* zoning, taxation, interest rates, and so forth; and
4. *The transportation system:* road, transit, and so forth.

The extent to which these various drivers are treated as being exogenous or endogenous to the model will vary from one modeling system to another. Government policies and changes to the transportation system are almost exclusively treated as exogenous inputs; demographic and regional economic processes are almost always treated as at least partially endogenous. Regardless, the full range of drivers of land use/location/travel decision-making should be included in the modeling system to ensure that the effect of any one policy (such as a change in the transit system) can be properly represented and evaluated by the model.[6]

[5] See Chapter 3 of the Final Report for more detailed discussion of this point.

[6] It was often the case with early land use models that they overemphasized transportation system effects on land use/location processes and, hence, tended to overpredict the effect of transportation system improvements on these processes. As Knight and Trygg (1977) demonstrate, however, transportation improvements are only one among many determinants of land development decisions.

Table 2 elaborates on the concept by presenting a set of technical axioms on which the 'ideal' model is based. Some of these axioms involve assumptions concerning real-world behavior. Others express basic strategies for modeling this behavior. They are axioms in that they are hypotheses, which are largely untestable, but if accepted as "true," they can form the basis for an internally consistent modeling system.

4.3 THE 'IDEAL' INTEGRATED MODEL: AXIOMS AND ATTRIBUTES

Table 3 summarizes the attributes of the ideal integrated urban model discussed above. These attributes are grouped according to three main categories: physical system, decision makers, and processes. Land development, location choice processes, and job-worker links are all modeled as economic markets with explicit supply and demand functions and procedures for price determination and "market clearing" (i.e., the allocation of supply to demand). The model is envisioned to be dynamic, disaggregate, and behaviorally sound. As such, it will be sensitive to a wide range of land use and transportation policies and will be able to trace the direct and indirect effects of any of these policies through time and space.

No attempt is made to specify detailed formulations of individual submodels within the overall modeling system. Many options typically exist here, and much research is required in order to translate this very general model into operational practice. Similarly, no attempt is made to address the data and computational requirements of such a model, except to note that such a modeling system is almost certainly not beyond our current and emerging capabilities (Miller and Salvini, 1998).

TABLE 2 Integrated urban systems—modeling axioms

1. In referring to the urban system, the focus is on those elements that influence and/or interact with the transportation system. Notwithstanding, the model should be extensible as appropriate.
2. The urban system consists of physical elements, actors, and processes. The modeling representation of this urban system must contain all three of these.
3. The transportation system is inherently multi-modal and involves the flows of both people and goods.
4. Markets represent the basic organizing principle for most interactions of interest within the urban area, providing price and time signals to producers (suppliers) and consumers (demanders) of housing, transportation services, and so forth.
5. Flows of people, goods, information, and money through time and space arise as a derived demand from market interactions that are distributed in time and space.
6. Urban areas are open, dissipative systems subject to external forces. As such, they never achieve a state of equilibrium.
7. The future is path-dependent. In order to generate a forecast year-end state, the model must explicitly evolve the system state over time.
8. The model must address both short-term (e.g., activity/travel) and long-term (e.g., land development, transportation infrastructure, and so forth) processes. There must be feedback/interaction between the processes.
9. Some factors and processes are clearly exogenous to the urban system per se. Others may be treated as exogenous as a modeling strategy.
10. Some activities within the urban area are 'basic' in the sense that they arise in response to external demand.
11. The ideal model should be conceptualized at a very fine level of representation (i.e., analytical units) so as to maximize "behavioral fidelity" in the representation of actors and processes, recognizing that any practical implementation probably will occur at higher levels of aggregation.

4.4 INVENTORY OF CURRENT MODELS

Given current technical capabilities (e.g., computer hardware and software, datasets and data collection capabilities, modeling techniques, and theoretical understanding of behavioral processes) and a concerted research and development effort, it is possible to develop and achieve the ideal integrated modeling system outlined in the previous section. As a starting point, however, it is important to compare the current state of the art in integrated models with the ideal model.

Although integrated or semi-integrated urban models exist, they vary in completeness and usability. Wegener (1995) identified 20 active urban modeling centers (i.e., models) around the world, of which approximately 12 integrated urban models were sufficiently operational to have been used for actual research and/or policy analysis in particular urban areas. Southworth (1995) identifies a further three models.

Undoubtedly the three best known integrated models in the United States are ITLUP (often referred to as DRAM/EMPAL), MEPLAN, and TRANUS. The three models have the following features in common:

- They are operational, commercially available packages.
- Each has an established history of use.
- Each has been applied in the United States in at least one practical setting (i.e., in an MPO).

Also of interest are three other models: MUSSA, NYMTC-LUM, and UrbanSim. These are noteworthy for two main reasons:

- Each is operational or sufficiently close to being operational, in a practical setting.
- Each contains a significant market representation (i.e., there is an explicit treatment of prices in land development).

A detailed comparison of these six models resulted in three important conclusions (Miller et al., 1998):

TABLE 3 Summary of ideal integrated model attributes

PHYSICAL SYSTEM	**Public Authorities:** Represented within the model to the extent they generate purely endogenous effects (e.g., employers of workers, demander/supplier of services, and so forth). Will remain represented largely by exogenous inputs to the model.
Time: Dynamic evolution of the system state in 1-year time steps. System state generally not in equilibrium. Interactions between long-term and short-term processes are "properly" accounted for.	**PROCESSES**
Land: The basic unit of land is the individual lot.	**Markets:** Land development, residential housing, commercial floor space, and labor all function within economic markets, which possess demand and supply components, and price signals, which mediate between demand and supply. These economic markets must be explicitly modeled if their behavior over time is to be captured properly.
Building Stock: Building stock is explicitly represented. Each lot has a certain amount of floor space, characterized by type, price, and so forth.	**Demographics:** Demographic processes should be modeled endogenously so as to ensure that the distribution of population attributes (personal and household) are representative at each point of time being modeled and are sufficiently detailed to support the behavioral decision models being used.
Transportation Networks: Full, multimodal representation of the transportation system used to move both people and goods. Sufficient spatial and temporal detail to properly model flows, network performance, emissions, and so forth. Ideally, a 24-hr network model to be used.	**Regional Economics:** Essential components of urban production/consumption processes should be modeled endogenously. The model should also be sensitive to macro exogenous factors (e.g., interest rates, national migration policies, and so forth).
Services: Sufficient representation of other services for the purpose of modeling land development decisions.	**Activity/Travel:** The travel demand component of the integrated model should be activity-based and sufficiently disaggregated so as to properly capture trip makers' responses to a full range of transportation policies, including ITS and TDM.
DECISION MAKERS	**Automobile Holdings:** Household automobile holdings (e.g., number of vehicles and by type) should be endogenously determined within the model.
Persons and Households: Both persons and households are explicitly maintained (with appropriate "mappings" between the two entities) in sufficient detail to model the various processes of interest.	
Firms: Explicitly represented. Firms are at least as important as households in the overall system: they occupy land/floor space; they employ workers; and they buy/sell goods and services from/to themselves and households. Firms are modeled in sufficient detail to capture adequately their behavior within these various roles.	

1. *All currently operational models fall short of the ideal model to varying extents.* Areas of significant shortfall in most models include the following:
   - Excessive spatial aggregation;
   - Excessive reliance on static equilibrium assumptions (with associated assumptions of large time steps and lack of path dependencies);
   - Overly aggregate representations of households and firms, as well as a lack of representation of individuals as decision-making units separable from their households;
   - Lack of endogenous demographic processes;
   - Lack of endogenous automobile ownership processes; and
   - Reliance on four-stage travel demand modeling methods.
2. *At the same time, current models individually and collectively display many strengths and generally provide a solid basis for further evolutionary improvements.* Strengths include the following:
   - Generally strong microeconomic formulations of land and housing/floor space market processes,
   - Coherent frameworks for dealing with land use-transportation interactions,
   - Multimodal transportation network analysis capabilities,
   - Experience with developing and using large-scale integrated models,
   - Integration (at varying degrees of progress) with "off-the-shelf" microcomputer capabilities, and
   - Integration (again at varying degrees of progress) with GIS and other disaggregate data bases.
3. *Despite the potential for significant evolutionary development of existing models, a new generation of integrated models will need to be developed in order to fully achieve the ideal model.* Although newer models (e.g., MUSSA and UrbanSim) point the way to more disaggregate and/or more dynamic models, much research and development must be undertaken in order to fully achieve the ideal model. This will include development of and experimentation with model structures explicitly designed to operate in a more disaggregate, dynamic, non-equilibrium framework.

SECTION 5

LINKING THE PRESENT WITH THE FUTURE

5.1 A TWO-PART APPROACH

How can the ideal future model be achieved? The three conclusions outlined in Section 4.4 above led to the following recommendations for a two-part program:

- *A research and development* program, directed toward producing the ideal, next-generation integrated model.
- *Evolution* of existing capabilities and data in order to maximize current potential, quickly and at minimal cost, while moving the state of the practice toward the ideal integrated model.

This two-part approach recognizes that the development of the ideal, next-generation model requires a dedicated research and development effort. A solid basis for this effort can be established by building on existing capabilities and data, although eventually the returns to scale will diminish and would be surpassed by the results of the research and development effort. Chapter 5 discusses the proposed research and development program. Chapter 6 of these guidelines outlines strategies and steps to advance the state of the practice (i.e., the evolutionary part of the program).

As a first step in the discussion, Section 5.2 classifies current and future land use and transportation modeling capabilities. MPOs and other practitioners can use this classification system to identify their current capabilities and the likely evolutionary paths for improving these capabilities. (This classification system recognizes that different cities are at different points along the evolutionary path.) The classification system is then used to identify development paths toward the achievement of the ultimate long-term product (i.e., the ideal, next-generation integrated model). Six incremental levels (ending with the ideal model) are identified.

Next, Section 5.3 describes the types of actions and strategies that allow movement along the development path. The context is drawn from the 1995 TMIP conference on integrated modeling, which generated a wide range of recommendations for improving the state of the art. Section 5.4 outlines the proposed research and development program.

5.2 CLASSIFYING INTEGRATED MODELING CAPABILITIES

The state of a planning agency's capabilities with respect to transportation and land use modeling can be summarized in a two-dimensional matrix such as that shown in Figure 3. In this matrix, rows correspond to different levels of land use modeling capability. Although a continuum of levels obviously exists, five significant land use modeling 'states' or capability levels are identified in Figure 3:

L1. **None.** The planning agency does not in any way model or forecast land use. Zonal population and employment data, if required for travel demand modeling purposes, are obtained from other agencies.
L2. **Activity + judgment.** Activity levels are estimated, perhaps on a scenario basis, and systematically allocated to zones. Methods are often spreadsheet-based and usually involve considerable professional judgment.
L3. **Non-market-based land allocation model.** A formal land use model is used, but this model is not market-based (i.e., it does not include endogenous price signals or an explicit supply process). ITLUP is an example of this type of model.
L4. **Land allocation with price signals.** A formal model is used, which includes endogenous price signals, but does not include a full demand-supply market process representation. This type of model does not currently exist. The potential role of such a model—in light of the overall long-term goal—is discussed further below.
L5. **Fully integrated market-based model.** A full system of market-based supply-demand relationships with explicit prices is used. MEPLAN, TRANUS, MUSSA, NYMTC-LUM, and UrbanSim are all current examples of this modeling approach, as is the 'ideal' model.

Similarly, the columns in Figure 3 represent different levels of travel demand modeling capability, of which four are shown:

T1. **No transit or mode split model.** Only roads and automobile travel are modeled.
T2. **Transit with simplified (non-logit) mode split.** Transit is represented in the modeling system, but modal split is performed using simplified (non-logit-based) methods. Assignments are usually based on daily (24-hr), rather than peak-period, volumes, usually using some form of capacity-restrained assign-

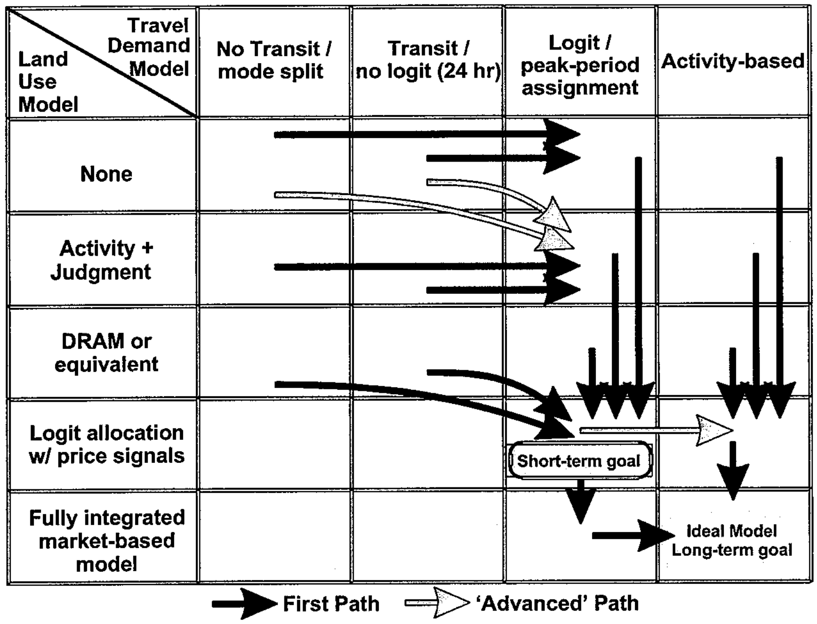

Figure 3. A taxonomy of transportation-land use modeling capabilities.

ment. The modeling system is not usually iterated to achieve internal consistency.

T3. **Logit mode split; peak-period assignment.** A disaggregate logit or nested logit mode choice model is used. Peak-period equilibrium assignment is used. The system is iterated to achieve internal consistency. This level of travel demand modeling capability essentially defines the current "best practice" for medium to large cities.

T4. **Activity-based methods.** This is an emerging approach (i.e., it goes beyond current best practice). The traditional four-stage process is replaced to varying degrees by activity-based (as opposed to trip-based) models. Portland, Oregon, is the most advanced along this path of model development in the United States, by far, with a few other cities experimenting to varying degrees. The thrust of "Track D" of TMIP is to move U.S. modeling practice toward this next-generation travel demand modeling approach.

Each cell in the Figure 3 matrix represents a transportation-land use modeling combination. Virtually all cities can be categorized as being currently contained within one of the 20 cells in this matrix. Points to note about this matrix include the following:

- There are six desirable incremental capability levels, as located by the arrowheads on Figure 3:
  1. Logit/peak-period assignment model/no land use model (T3, L1).
  2. Logit/peak-period assignment model/'activity + judgment' land use model (T3, L2).
  3. Logit/peak-period assignment model/logit allocation land use model with price signals (T3, L4). This represents a short-term goal.
  4. Logit/peak-period assignment model/fully integrated market-based land use model (T3, L5).
  5. Activity-based travel demand model/logit allocation land use model with price-signals (T4, L4).
  6. Activity-based travel demand model/fully integrated market-based land use model (T4, L5). This represents the long-term goal of the ideal integrated model.
- "Appropriate" combinations of transportation and land use modeling capabilities tend to lie along the major diagonal (i.e., from upper left to lower right). It makes little sense to combine a very complex land use model with a very crude travel demand model or vice versa (although there are cities that have sophisticated travel demand models with little or no land use modeling capability).
- The "appropriate" cell for a given city obviously depends on several factors, including the city size, the nature and extent of its transit system, and the extent to which it is interested in pursuing land use as a policy tool.

The arrows in Figure 3 depict logical/recommended "development paths" or trajectories for urban areas desiring to upgrade their modeling capabilities, where the base of the arrow represents a current capability (e.g., L1, T1: no land use model and no transit representation) and the tip of the arrow represents a logical incremental upgrade on that capability (e.g., L1,T3: no land use model, best practice travel demand model).

In specifying these development paths, several principles and assumptions were invoked. These include the following:

- Practically, it is not possible to develop a credible land use model (at least beyond the spreadsheet accounting/judgment level) without having a well-developed travel demand model. Thus, an urban area's first priority should be to ensure that it has an operational 'best practice' travel demand model in place before taking on any significant land use modeling tasks.[7]
- Given the comments in the previous section concerning the attractions of an incremental, evolutionary approach to model development, only "short jumps" of one or two cells are generally shown in Figure 3. Thus, even if the long-term objective is to move from the upper left corner of the matrix (i.e., virtually no modeling capability) all the way to the lower right (i.e., the ideal model), one should accomplish this in several stages. Each stage is defined by a clear operational product that represents a significant improvement over the previous modeling state. It also provides a solid base (in terms of data and operational experience and so forth) for the next step forward.

Figure 3 shows a short-term goal of the L4, T3 model combination. This is seen as a realistic objective for advancing the state of the practice in integrated modeling in advance of the long-term realization of the ideal model, for two reasons:

- It reflects a travel demand model structure (logit/peak-period assignment) that is relatively well advanced which, therefore, can draw from a wide body of literature and practical installations. Therefore, it is readily achievable.
- The class of land use model (land allocation with price signals) represents an improvement over non-market-based land allocation models, but does not require a complete, fully integrated market-based model. Although, as discussed below, this class of land use model does not yet exist operationally, it represents an attractive short-term advancement toward the ideal long-term model.

Finally, Figure 3 shows 'first' and 'advanced' paths of development. The ordering of movement is important, because—as noted above—advancements in both types of models are linked and, therefore, must be coordinated. Two advanced paths are noted:

- Movement from minimal travel demand/no land use modeling (L1, T1 or L1, T2) capabilities is recommended first toward improvements in travel demand modeling (T3), then in land use modeling (i.e., horizontally then vertically). But it also is practical to augment this simultaneously with a corresponding improvement toward minimal land use modeling capability (L2).
- More important is the sequence of movements from the short-term goal (L4, T3) to the long-term goal (L5, T4). Here, the recommendation is to advance first toward a fully integrated market-based land use model (L5), then toward an activity-based travel demand model (T4). This sequence reflects the more advanced operational status of market-based land use models compared with activity-based travel demand models. However, an acceptable alternate treatment is the reverse order: T4, then L5.

Specific steps on how to undertake these various model development paths are discussed in Chapter 6.

Three activities drive the research and development part of the program (i.e., in terms of Figure 3, the development of the short- and long-term models):

1. *Financial and technical support for cities wishing to undertake these types of model upgrades, especially with respect to improving their land use modeling capabilities.* Financial and technical resource constraints have been identified above as major obstacles to improving integrated urban modeling capabilities.
2. *Considerable basic and applied research is required to turn the ideal model described in Chapter 4 into an operational system.* The effort required is described in detail in Chapter 6 of the TCRP Project H-12 Final Report.
3. *The "L4: land allocation with price signals" type of model does not currently exist as an operational model.* It represents a gap between current non-market models (e.g., ITLUP) and "fully elaborated" market models (e.g., MEPLAN and MUSSA). This is a significant gap, in that it represents an important and attractive intermediate capability, which may well prove useful in many urban areas, either as an end point for model development (i.e., "good enough" for local purposes) or as an important step in the evolution toward a full market-based system. This is elaborated in Appendix B of the Final Report, which provides a more detailed discussion of the proposed model.

5.3 CONTEXT: THE 1995 TMIP DALLAS CONFERENCE

In February 1995, TMIP sponsored a conference in Dallas, Texas, on land use modeling. This 3-day workshop-based conference was attended by 80 professionals drawn from academia, government, and consulting, primarily from within the United States but also from abroad. It generated a wide range of recommendations to improve integrated urban modeling; the recommendations recognized the need for both evolutionary improvement in existing methods and the

[7] Caveats may exist here with respect to small urban areas, within which transit services may be minimal or even non-existent. In such instances, integrated models without a significant transit/mode split modeling component may be used.

development of new models. The recommendations are summarized in Table 4.[8]

5.4 RESEARCH AND DEVELOPMENT PROGRAM

5.4.1 Approach

A key product of TCRP Project H-12 was a recommended research and development program to develop the ideal, next-generation integrated model. The program is described in the following sections. Section 5.4.2 identifies several principles and requirements that provide a context for the discussion. Section 5.4.3 summarizes the long-term research and development program. Of particular importance, the program proposes a "case study" mechanism for upgrading or implementing integrated modeling capabilities. The mechanism, summarized in Section 5.4.4, requires nationwide coordination of activities.

5.4.2 General Principles and Requirements

The overall goal of the evolutionary process is to improve integrated land use-transportation modeling capabilities by moving along the development paths shown in Figure 3. Four general principles guide this movement:

1. *Data must be obtained first.* Priority must be given to ensuring that the data required by the models are sufficiently comprehensive and complete. This is true regardless of the current or desired capability level or the development path chosen.
2. *Travel demand modeling capabilities are a necessary condition.* With some exceptions, it is generally essential that travel demand modeling capabilities be upgraded *before* upgrading the land use model.
3. *A step-by-step approach is required.* Only an incremental/evolutionary approach is realistic.
4. *A plan is required.* Several increments may be required or desired. A plan ensures that the incremental steps are consistent and will lead to the desired outcome.

These are elaborated below as ten guiding principles and requirements. Because most apply to all models, integrated and otherwise, some may be well known to experienced modelers; however, they are worth repeating because of their fundamental importance.

1. *Data are of overwhelming importance.* Data are crucial in the development, application, interpretation, and updating of a model. The acquisition of data is part and parcel of model development. Good data are useful in and of themselves in the overall planning analysis, in both understanding today's situation and diagnosing problems and needs. Data also provide a context for model outputs.

   Many (if not all) transportation planning agencies have acquired or are moving toward GIS as the primary means of storing, managing, and displaying transportation data. The next generation of models very likely will be compatible with GIS. Therefore, a data strategy for implementing, modifying, and/or upgrading existing or planned GIS capabilities should be put in place. Equally important is the need for an ongoing commitment for the acquisition of data and their management; both for modeling purposes and as part of a comprehensive corporate data program.
2. *Staff resources must be developed.* Such development ensures that an agency has sufficient in-house expertise and that personnel are appropriately trained. There is a need for staff who are dedicated to and responsible for the model. These staff must understand the theory and operation of models, as well as how the models are to be used in policy and planning analyses and, especially, in how the model outputs are to be used in decision making. Staff must be aware of and be able to identify clearly the statistical and practical limitations to the use of model outputs (i.e., they must be capable of evaluating and interpreting the results).

   There is a need for outside help to complement in-house staff in developing the model—it is very difficult for in-house staff to address both daily on-line operational functions and model development at the same time. Model development usually also requires additional expertise from consultants, researchers, and so forth. This is cost-effective in the long run, because it allows an agency to avoid duplicating the efforts of others and promotes faster completion of the model.
3. *A dedicated commitment must be made to the development of the model, separate from daily operations.* The development of any tool requires a dedicated effort and recognition that some time is required. The process must be somewhat isolated from day-to-day planning activities in order to avoid drawing resources from the model development into daily activities and to ensure that the model development is not inadvertently redirected to focus on short-term needs. Too often, model development is linked to a specific project or policy question; development is rushed (if not also compromised). Although short-term needs are met, the long-term application of the model can yield less than optimal, even unusable, results.
4. *Managerial/institutional commitment is required.* Models and data are not typically 'front-line' products

[8] For full documentation of the conference, including workshop reports and plenary papers, see Shunk et al. (1995).

TABLE 4 Summary of Dallas conference recommendations

General Recommendations

- Need for comparative descriptions of existing models to support informed choices by agencies adopting models.
- Need for guidelines/advice in the use of integrated urban models.
- Pilot programs should implement a range of models from which experience and guidance could be developed.
- Models should address a wider range of policies, including environmental issues.
- Models should consider actions of individuals, governments, developers, businesses, and investors.
- Models should be "modular," to permit intervention to adjust data and to address varying levels of spatial and temporal resolutions, on a problem-specific basis.
- Modeling systems should take full advantage of Geographic Information System (GIS) capabilities.

Recommendations for Improving Existing Models

- More direct links to GIS required.
- Comparative descriptions and evaluations of existing models required.
- Time-series validation of models required.
- Improving the availability and quality of employment data the single highest priority item.
- More rigorous methods for judging reasonableness of model results required.
- Methods for sketch planning level evaluation of transportation effects on land use are required.
- Need exists for improved feedback among existing land use, transportation, and environmental models.

Recommendations for New Model Development

- New models must be behaviorally based, with clear theoretical foundations.
- Major research is required into the behaviors of the actors involved.
- Models should emphasize policy analysis, planning, and sensitivity testing, within an integrated land use, transportation, and environmental framework.
- Models should be able to vary temporal and spatial scales, adjusting to the problem being analyzed.
- Micro simulation holds promise, but much research is required to develop the method and to resolve issues concerning its data requirements (which are potentially huge).
- Other methods, however, should also be investigated and might prove more suitable in some contexts.
- Model development should draw on a range of disciplines, not just transportation modeling/planning. Location choice models must depend on a full range of factors affecting these choices, not just travel costs/times.
- Models must be integrated with GIS. Remote sensing should be investigated as a means for collecting/updating land use data.
- The minimum time frame for new model development may be 5 years.

Source: Adapted from Weatherby (1995).

of a planning agency. They commonly operate in the background. However, because their outputs will be used by senior decision makers and politicians, the role of the model must be fully understood and recognized within the organizational structure. Successful modeling always begins with a management commitment to the concept. An ongoing commitment of time and resources is related to the conceptual commitment; at the same time, modeling staff must be able to keep management fully informed on the progress of the model.

5. *Include the modelers in decision-making.* Modelers must understand the policy and planning process (i.e., to what the model will be applied). Decision makers, policy analysts, and planners must understand what the models can and cannot do, what questions they can answer, and how to interpret the results
6. *Understand the proper roles of the model.* This is a fundamental requirement for model applications. Modelers must understand and be able to make decision makers understand that a "model" is only that: it is an isolated representation of a real-world process that allows us to understand how that process works and how that process may react to different conditions. A model cannot address all issues definitively. A model is a decision-support tool—not the provider of the "answers."
7. *Do not underestimate or dismiss models.* Models have and can play an important role within the planning process. Specifically, models provide the following:
   - A means of systematically exploring assumptions,
   - A check on judgment and intuition,
   - The only means to systematically and consistently explore complex systems, and
   - A means for everyone to learn about a system's cause-and-effect relationships.
8. *Do not settle for too little.* The practical forward movement of modeling capabilities requires an incremental, step-by-step approach. Each step necessarily is complex and requires its own commitment of time and resources. However, it is essential that the forward movement be maintained.
9. *Do not accept the status quo.* Similarly, the existing modeling capability level—regardless of how close it is to the current state of the art—should not be considered as the end.
10. *Move incrementally, but move toward the long-term plan.* Progress must be measurable, with definable and observable products.

5.4.3 Research and Development Program

Figure 4 summarizes the proposed research and development program for significantly improving the operational

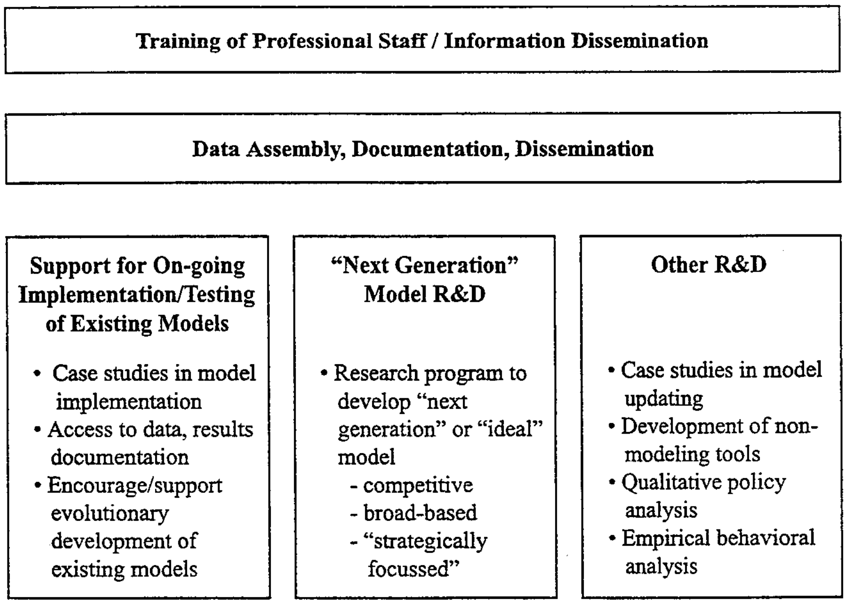

Figure 4. Elements of R&D program for integrated urban models.

state of practice in integrated urban modeling over the next 5 years. As shown in the figure, this program consists of five closely related components:

1. Training of professional staff and dissemination of technical information;
2. Data collection, assembly, documentation, and dissemination;
3. Implementation and evolutionary development of existing models;
4. Development of the next generation of urban models; and
5. "Non-model-based" (complementary) research and analysis designed to improve both our understanding of land use and transportation interactions and our ability to analyze urban policies.

The first two of these components (training and data) support and are interconnected with all other tasks. The other three components represent largely parallel activities that typically would be undertaken by different groups of researchers, model developers, and so forth, depending on their strengths and interests (although "information flow" among these parallel tasks would be maintained by the overarching information and data dissemination components).

The research and development program is described in detail in Chapter 6 of the Final Report. It is presented here essentially without discussion, except to note that the six capability levels identified in Section 5.2 above can be developed within this framework. The research and development program is designed to encourage debate, as well as a multiplicity of opinions and contributions to the development of the ideal integrated urban model. The intent is to draw on existing resources and knowledge bases, while building on existing modeling capabilities. At the same time, the overall program must be coordinated, sponsored, and promoted by a central body (or bodies), and specific activities (e.g., information dissemination) should be done at a single, national level, rather than as multiple, subnational diffusions.

5.4.4 Case Study Mechanism

The case study approach for upgrading existing modeling capabilities provides a way to move along the development path illustrated in Figure 3 and, therefore, a way to improve the current state of the practice. The case study approach is described below (see also Section 6.5.2 of the Final Report).

The approach is designed, in part, to address two common barriers to the more widespread use of integrated models: the lack of in-house resources (i.e., insufficient expertise and money to implement a model) and the lack of well-documented "success stories" that can encourage agencies to proceed with the modeling effort and can provide practical references.

One mechanism for conducting the case studies is to develop several "modeler-MPO" partnerships to upgrade and/or implement integrated models in a practical, coordinated, and focused manner. Key elements of this proposed program are as follows:

- The "modeler" might be a university research group, an integrated urban model developer, or a consulting firm.
- Each case study would consist of four phases:
  1. Model (site) selection/verification,
  2. Model implementation,

3. Model testing (i.e., in real-life (policy) applications of local interest), and
4. Steady-state use (i.e., the MPO should be able to maintain and operate the model for routine agency use, perhaps with some support from the modeler).

- Extensive documentation of the four phases of each case study must be maintained and openly disseminated.
- An important part of each case study must be the development of new data bases or the updating of existing sources. These must include the "standard" socioeconomic/demographic and travel data bases (e.g., population, land use, and travel O-D). However, special attention also must be given to the development of other, traditionally problematic, data that are essential to the development of the more advanced land use models (e.g., employment, price data, and firm location choice).
- Taking into account the need to ensure adequate applicability of the results, case studies also must be awarded to modeler-MPO partnerships on an open, competitive basis. Thus, modeler-MPO partnerships must meet the following minimum requirements:
  - Demonstrated capabilities of the modeler to undertake the proposed implementation,
  - Demonstrated capability and interest of the MPO to support the model implementation and to maintain and use the model,
  - Demonstrated capability of the modeler and MPO to work together,
  - The technical quality of the proposed model implementation (the proposed model should meet or, preferably, exceed an explicit set of minimum technical standards), and
  - The potential for innovation within the model implementation (e.g.,extensions of capabilities of existing models and introduction of new modeling methods within an operational setting).
- Case studies should be selected on the basis of recommendations from an independent peer review panel. This panel would be directed by, or be part of, the program management group. The panel should also review the model implementation and testing results in each case, specify the "standard tests" to be performed, and undertake the cross-comparisons of standard test results obtained from the case studies.

Benefits of the proposed case study program include the following:

- It directly improves the state of practice in many locations.
- It provides operational experience that can be extrapolated elsewhere.
- It is a cost-effective means for controlled experimentation.
- It provides a practical, direct way to improve data bases for both operations and research.

SECTION 6

IMPROVING THE STATE OF THE PRACTICE

6.1 OVERVIEW

This chapter focuses on the short-term, evolutionary development of integrated model capabilities. It uses the six capability levels as the possible "targets" for this development (identified in Figure 3 and listed in Section 5.2). The chapter provides guidelines and checklists for the use of MPOs and other agencies that wish to upgrade their capabilities. Section 6.2 provides some general guidelines and expands on the 1995 Dallas TMIP conference recommendations. Section 6.3 identifies the components of the six capability levels. Finally, Section 6.4 discusses the representation of transit in existing travel demand forecasting models.

6.2 GENERAL GUIDELINES FOR THE DEVELOPMENT OF INTEGRATED MODELS

These components must be placed in the context of the recommendations of the 1995 Dallas conference (Table 4). Specifically, the conference made seven recommendations for improving existing models. Each of these recommendations applies generally to the achievement of the six incremental capability levels as follows (adapted from Shunk et al. [1995]):

1. *GIS links are required.* The availability of GIS in a planning agency generally must be considered as a given. Many of today's commercially available travel demand forecasting models have links with some of the more widely used GIS packages; there exists at least one commercial model built into a GIS. However, with that one exception, many of the links are unidirectional, in which model networks are derived from GIS network definitions (but the GIS cannot easily import the model networks). Customized integrations exist, in which various components of model networks, matrixes and processes can be exchanged with a GIS. At least one integrated model (DRAM/EMPAL) has a GIS interface.

   A full GIS interface would permit the bi-directional exchanges of data and would support the exchange of matrixes and processes as well as model networks.

   Numerous GIS packages are in use among planning agencies and a single standard for data exchange does not yet exist. In addition, many GIS have been established primarily for design, operational, and maintenance purposes (where data requirements can differ from those of planning needs [e.g., connectivity is an essential requirement for a transportation model network, but is not necessarily needed for design purposes]).[9] Other needs include the need for disaggregation of data inputs. Therefore, modeling and planning requirements must be incorporated early in the development of a GIS (and modeling initiatives must take account of GIS).
2. *Comparative descriptions and evaluations of existing models are required.* The lack of a common overall algorithm, the many initiatives taking place around the world, and the different levels of land use modeling capabilities make comparing existing modeling capabilities difficult. Several attempts have been made in recent years; including an inventory of current capabilities in Chapter 5 of the Final Report. Other comparisons include Wegener (1995) and Southworth (1995). In addition to providing an indication of the technical capabilities of existing models, from which their applicability to a particular situation can be determined, these comparisons also provide a useful source of evaluation criteria.
3. *Time-series validation of models is required.* The development program of any of the six incremental modeling capabilities should include model validation, either through "back-casting" or by building in an ability to monitor forecast results over time.
4. *Employment data must be improved.* Improving the availability and quality of employment data was considered by the 1995 Dallas conference to be the single highest priority item. As movement progresses toward the inclusion of pricing mechanisms and signals in the land use models, it also will be necessary to include and analyze "space prices" (e.g., development and rents).

[9] Connectivity requires that all links are "physically" connected to each other in the GIS. This is not always the case, because links may be depicted in the GIS as separate, individual entities.

5. *Better means of assessing model outputs are required.* More rigorous and systematic methods for judging the reasonableness of model results are required. These must be based on mathematical and statistical goodness-of-fit measures and must include "reasonableness" checks. These must be considered in the planning and specification of any model development program.
6. *Sketch planning methods for evaluating land use-transportation effects are required.* Methods for sketch planning level evaluation of transportation effects on land use (and vice versa) are required. These are likely to represent a different level of complexity from the modeling initiatives discussed here; however, one implication is that any model development program should explicitly consider how the results are to be presented and tabulated and how the results can be interpreted and documented for future use in sketch planning.
7. *Improved feedback is required* among existing land use, transportation, and environmental models. Each of the six incremental capability levels aims to implement and improve feedback. Any model development program must explicitly test and control for different "scenarios" in order to be able to isolate, monitor, and analyze the feedback effects (e.g., the expected different effects on transportation of compact versus sprawl land use distributions).

6.3 CHECKLIST—COMPONENTS OF THE SIX CAPABILITY LEVELS

The components of each of the six incremental capability levels are summarized in Table 5. These can be achieved within the case study mechanism, described in Section 5.4.4, but also could be pursued by individual transportation planning agencies and transit operators.

Table 5 can be used as a checklist. The table summarizes input data requirements, as well as the main components of

TABLE 5 Components of each capability level

Desired State	1. Logit/peak-period assignment model (T3)/ No land use model (L1)	2. Logit/peak-period assignment model (T3)/ "Activity + Judgment" land use model (L2)
Input data	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space
Transportation model components	• Detailed road and transit network • Demand modeling (trip generation, distribution, modal split): peak period. • Trip generation: multi-modal; account for Automobile Ownership • Trip distribution: multi-modal (account explicitly for effect of transit on accessibility) • Modal split: logit-based binomial/multinomial; account for Automobile Ownership • Trip assignment: multi-modal, peak hour assignment	• Detailed road and transit network • Demand modeling (trip generation, distribution, modal split): peak period. • Trip generation: multi-modal; account for Automobile Ownership • Trip distribution: multi-modal (account explicitly for effect of transit on accessibility) • Modal split: logit-based binomial/multinomial; account for Automobile Ownership • Trip assignment: multi-modal, peak hour assignment
Land use model components	N/A (demographic/economic data provided as stand-alone inputs only)	• Various actions; each of which is intended to encourage some degree of feedback between the travel demand forecasting model and the land use forecasting process: – Testing of alternate land use scenarios (manual, indirect feedback only) – Development of transportation-based land use scenarios (manual, indirect feedback only): • compact v. sprawl development patterns • high densities on transit corridors • mixed-use activity centres (and so forth)

(continued on next page)

TABLE 5 ***(continued)***

Desired State	3. Logit/peak-period assignment model (T3)/ Logit allocation land use model with price signals (L4)	4. Logit/peak-period assignment model (T3)/ Fully integrated market-based land use model (L5)
Input data	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – zoning, taxes and subsidies – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space – space prices (housing, commercial, and so forth)	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – zoning, taxes and subsidies – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space – space prices (housing, commercial, and so forth)
Transportation model components	• As per desired states 1 and 2 (T3)	• As per desired states 1 and 2 (T3)
Land use model components	• Land use model: distributes space (activities) as a function of travel accessibilities and costs; demographic/economic (space) totals and distributions; and activity distributions from time t to distribute activities in time $t+1$ as a function also of (land) developer activity; space prices in time $t+1$. • Developer sub-model: simulates creation of built space, as a function of space prices, space zoning and taxes, subsidies	• Land use model: distributes space (activities) as a function of travel accessibilities and costs; demographic/economic (space) totals and distributions; and activity distributions from time t to distribute activities in time $t+1$ as a function also of (land) developer activity; space prices in time $t+1$. • Developer sub-model: simulates creation of built space, as a function of space prices, space zoning and taxes, subsidies

Desired State	5. Activity-based travel demand forecasting model (T4)/ Logit allocation land use model with price signals (L4)	6. Activity-based travel demand forecasting model (T4)/ Fully integrated market-based land use model (L5)
Input data	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – zoning, taxes and subsidies – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space – space prices (housing, commercial, and so forth) – activity prices (job market)	• Multi-modal transportation network and services description, attributes and costs • Multi-modal travel characteristics: – origin-destination surveys, counts (and so forth) • Demographic/economic data (totals/distributions): – zoning, taxes and subsidies – households/occupants/Automobile Ownership – employment – school enrollment – retail, and so forth, floor space – space prices (housing, commercial, and so forth) – activity prices
Transportation model components	• Detailed multi-modal road and transit networks • Activity-based demand modeling • Disaggregate-level simulation • Explicit inclusion of goods movement	• Detailed multi-modal road and transit networks • Activity-based demand modeling • Disaggregate-level simulation • Explicit inclusion of goods movement
Land use model components	• Land use model: distributes space (activities) as a function of travel accessibilities and costs; demographic/economic (space) totals and distributions; and activity distributions from time t to distribute activities in time $t+1$ as a function also of (land) developer activity; space prices in time $t+1$. • Developer sub-model: simulates creation of built space, as a function of space prices, space zoning and taxes, subsidies • Full treatment of urban production/consumption processes: household choice, job market, and so forth	• Land use model: distributes space (activities) as a function of travel accessibilities and costs; demographic/economic (space) totals and distributions; and activity distributions from time t to distribute activities in time $t+1$ as a function also of (land) developer activity; space prices in time $t+1$. • Developer sub-model: simulates creation of built space, as a function of space prices, space zoning and taxes, subsidies • Full treatment of urban production/consumption processes: household choice, job market, and so forth

the travel demand forecasting model and the land use model. Some of the capability levels are only now being developed (e.g., activity-based travel demand models [T4]), do not yet exist (e.g., logit allocation land use model with price signals [L4]), or require further development (e.g., fully integrated market-based land use model [L5]).

Table 5 generally avoids the specification of particular algorithms or techniques, given the wide range of valid techniques available in general practice.

6.4 A NOTE ON THE REPRESENTATION OF TRANSIT IN EXISTING MODELS

Many commercially available travel demand forecasting models allow transit demand to be simulated in considerable detail. It can be said that the state of the art in modal split techniques, which is utility-based and uses disaggregate choice models, is fairly well advanced. This concerns the demand side. However, the supply side, that is, the assignment of transit trips and the representation of the traveler's choice (e.g., components of travel times, respective weights, reluctance to transfer, out-of-pocket costs, and so forth) can be problematic because of the following:

- The difficulty of simulating a complex urban transit network;
- The need to account for such difficult to measure attributes as travel time weights and value-of-time;
- The scale of calibration required to simulate major routes as compared with the simulation of major roads;
- That the transit share in most cities is smaller than that of the automobile and, therefore, there are relatively fewer observations on which to base the forecasts;
- That many transit investments consider modes that are new to a neighborhood or a region, the travel behavior for which cannot be considered simply as an extension of existing transit ridership patterns;
- That some models assign transit ridership on the basis of the rider's shortest path, with relatively little consideration of the effect of crowding or other capacity restraints on the rider's choice (compared with the automobile assignment, in which demand and capacity are more strongly related).

Many commercial travel demand models provide the capabilities for simulating transit ridership with some level of precision. Therefore, the issue may be more one of ensuring that the definition of data, networks, and land use is appropriate to the need at hand (and less an algorithmic issue). Data should be available at a level of detail appropriate to the issue in question (e.g., transit corridor). The model should be calibrated in a corresponding manner (e.g., at various points along the transit corridor—not just at screenlines).

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APPENDIX A

LEGAL CONTEXT FOR INTEGRATED PLANNING

A-1 OVERVIEW

Three Federal Acts are of primary relevance. These are as follows:

- ISTEA—the 1991 Intermodal Surface Transportation Efficiency Act;
- TEA-21—the 1998 Transportation Equity Act for the 21st Century, which succeeds ISTEA; and
- CAAA—the 1990 Clean Air Act Amendments.

Their implications on integrated land use-transportation planning and modeling are discussed below. The discussion is not exhaustive but is sufficient for the purposes of these Guidelines.

A-2 ISTEA

When it became law in December 1991, ISTEA fundamentally altered transportation planning in the United States. As Marshall (1997) explains, ISTEA changed the federal rules that govern state and metropolitan transportation planning. ISTEA has decentralized the former "top-down" transportation planning approach, in which federal mandates largely influenced the timing and location of new state highway construction, in favor of strengthening local and regional authority in transportation planning and decision making.

Weiner (1997, pp. 201–224) summarizes the relevant aspects of ISTEA and other relevant legislation governing transportation planning. ISTEA required metropolitan planning organizations (MPOs) to develop a 20-year metropolitan transportation plan. This long-range plan had to be based on a financially affordable and integrated[1] transportation system. Opportunity had to be provided for public input. The plan was to maximize use of the existing transportation system in finding ways to relieve congestion. In non-attainment areas, the plan also was to be coordinated with the development of transportation control measures that are required under the CAAA. The long-range plan had to be updated periodically.

Under ISTEA, the development of an MPO's long-range transportation plan had to take into account 15 interrelated factors. The fourth of these requires some integration of transportation plans and land use plans. Specifically:

> "the likely effect of transportation policy decisions on land use and development and the consistency of transportation plans and programs with provisions of all applicable short- and long-term land use and development plans."

ISTEA also required states to develop a continuous statewide transportation planning process, based on that used by MPOs for metropolitan transportation planning. A long-range, integrated,[2] multi-modal statewide transportation plan had to be prepared. It was to be coordinated with metropolitan transportation plans, and it was to allow for public input.

As with metropolitan transportation plans, the statewide plans had to consider 20 factors, of which the 14th was as follows:

> "the effect of transportation decisions on land use and land development, including the need for consistency between transportation decisionmaking and the provisions of all applicable short-range and long-range land use and development plans."

A-3 TEA-21

ISTEA's authorization of surface transportation programs expired in September 1997 (although funding allocations were extended to the spring of 1998). TEA-21—ISTEA's replacement—provides authorization for surface transportation programs for another 6 years. TEA-21 builds on ISTEA's initiatives, although in some cases with different emphases. Of relevance to integrated modeling, TEA-21 retains the general structure of metropolitan and statewide transportation plans described above. Of particular importance (House of Representatives, 1998, pp. H3810, H3812):

- TEA-21 has "streamlined" the planning process by replacing the aforementioned list of fifteen metropolitan planning "factors" (and twenty statewide factors) with a shorter, broader list of seven issues which transportation plans must "consider." <u>No specific reference is made to the integration of land use and transportation plans</u> under this provision. Issues that *could* be interpreted as including land use planning (i.e., which must be supported by the transportation plans) are:
  - Economic vitality of the metropolitan area (or, for statewide plans, the state and the nation as a whole), "especially by enabling global competitiveness, productivity and efficiency." (factor A)

[1] That is, integration of modes.

[2] Again, integration of modes.

- Protect and enhance the environment, promote energy conservation and improve quality of life. (factor D)

These interpretations are illustrative only—a definitive interpretation is not yet available, given that TEA-21 is relatively new. (Nor is such an interpretation appropriate to these Guidelines.)

- Failure to consider any of the seven streamlined factors is not "reviewable" in court, in any matter affecting a "transportation plan, a transportation improvement plan, a project or strategy, or the certification of a planning process."

Taken together, these two changes could be interpreted as suggesting a "softening" of the requirement for integrated land use-transportation planning. However, a more appropriate interpretation may be that integrated land use-transportation planning is now considered under the broader rubrics of economic growth and development, the environment, and energy considerations. The Conference Report on TEA-21 (House of Representatives, 1998, p. H3908) does establish the link, but softens the requirement ("encourage"), with the following wording:

> "In considering the relationship between transportation and quality of life, metropolitan planning organizations are encouraged to consider the interaction between transportation decisions and local land use decisions appropriate to each area. The language (i.e. of the seven streamlined factors) clarifies that the failure to consider any specific factor . . . is not reviewable in court."

Somewhat stronger wording appears as part of the project justification requirements for capital grants or loans. Here, the Report notes (p. H3857) that the justification for a "new fixed guideway (transit) system or extension of an existing fixed guideway system" must (among other things):

- ". . . recognize reductions in local infrastructure costs achieved through compact land use development;"
- "identify and consider mass transportation supportive existing land use policies and future patterns, and the cost of urban sprawl;" and
- "consider the degree to which the project . . . promotes economic development."

A-4 CLEAN AIR ACT AMENDMENTS (1990)

The 1990 CAAA built on previous versions of the Act. The 1990 amendments expanded the Act's conformity provisions (i.e., to attaining ambient air quality standards). A conformity determination was required, in order to ensure that federally approved or financed (in whole or in part) projects or actions conformed to a state implementation plan (SIP). SIPs are actions aimed at reducing vehicular emissions, in order for a metropolitan area to achieve National Ambient Air Quality Standards (NAAQS). The 1990 amendments required that transportation investments proposed by state DOTs or MPOs did not generate new violations of NAAQS or cause delays in the achievement of NAAQS (through the SIPs). The amendments also recognized that air quality must be analyzed quantitatively across the entire transportation system and could be controlled most effectively through regionwide strategies.

Thus, in effect, long-range transportation plans must show conformity to air quality control plans. The 1990 CAAA also expanded sanctions for federal-aid highway projects (i.e., if it was determined to increase emissions contrary to the SIP). At the same time, projects that could be seen as better managing or reducing automobile traffic (thereby controlling emissions) were exempted from sanctions, including transit capital projects.

A-5 IMPLICATIONS

A detailed discussion of the legal requirements of transportation planning is beyond the scope of these Guidelines. Nevertheless, four key points can be made:

- *ISTEA established a formal requirement for linking land use and transportation planning, although the TEA-21 is less clear.* Land use plans, of course, remain under local jurisdiction. Metropolitan and statewide transportation plans are under the jurisdictions of MPOs and state DOTs, respectively; but are governed by federal legislation and funding requirements.
- *The means of meeting the cited ISTEA/TEA-21 requirements are left unclear.* Given the different jurisdictional mandates involved, there may have been no practical way of being clearer. However, land use planning is taken into account in transportation funding for specific transit capital projects.
- *Together with CAAA, ISTEA established a link among land use planning, transportation planning, and air quality.* An important way of improving air quality is to reduce the demand for travel.[3] One way of achieving this is to introduce land use plans that promote alternatives to the automobile (e.g., through mixed-used, high-density development; transit- and pedestrian-friendly environments; and so forth).
- *There is a corresponding need for analytical tools and data that can support the land use-transportation-air quality link.* The dynamics of the link, and of the consequences of different actions, are not fully understood.

[3] Where "reducing" demand can be described in several ways: avoidance of any trip (e.g., through telecommuting), avoidance of automobile trips (e.g., through a shift to other modes), reduction of drive-alone automobile trips (e.g., through ridesharing), spreading demand outside peak hours (e.g., through tolls), reduction in overall trip length (e.g., through high-density, mixed-use developments), and so forth.

Moreover, this understanding must transcend jurisdictional responsibilities. Many pieces of the puzzle are in place (e.g., the many joint development analyses undertaken in the 1970s and 1980s; the wealth of information that has been developed over time on trip generation rates for specific land uses; and, most recently, the development of transit-friendly urban design guidelines). However, a comprehensive, overall framework in which these cause-effect relationships can be ordered and related is lacking.

TEA-21 explicitly recognizes the need for an improved understanding of this link. The *Surface Transportation-Environment Cooperative Research Program* provides for research "to improve understanding of the factors that contribute to the demand for transportation," including "demographic change" and "land use planning."

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APPENDIX B

GLOSSARY OF SELECTED MODELING TERMS

B-1 GLOSSARY OF SELECTED MODELING TERMS

This glossary includes selected modeling terms that are referenced in the modeling classification system described in Section 5.2. The glossary focuses on terms related to travel demand forecasting. The glossary is intended to explain briefly the basic concept and is not meant to be exhaustive; moreover, the descriptions are deliberately simplified, in the interest of brevity. More detailed treatments can be found in university textbooks, or specialty texts, on transportation planning and modeling.

1. ***Models*** are defined as mathematical algorithms that simulate human activities such as travel behavior. Once they are calibrated against existing (known) conditions, the models can be used to forecast these activities. For the purposes of these Guidelines, however, it is appropriate also to include theory and data, in addition to algorithms, in the definition of a model. This is because the successful development and application of any model involves a complex and balanced interaction among all three of these building blocks. The incorporation of "theory" provides a solid foundation for the model. "Algorithms" provide the means of translating theories into an operational reality. "Data" represent the inputs and the outputs, without which the algorithms neither function nor provide meaningful results.
2. ***Travel demand forecasting models*** are used to predict travel on a transportation network. Travel demand (i.e., traveler behavior) is a function of both human activities (generally represented in the models by land use; see below) and network characteristics (including the services provided and their costs; where costs generally are expressed in terms of time and/or money expended by the user and/or the transporter, and possibly intangibles such as comfort, and so forth). Therefore, travel forecasts will vary according to changes in human activities or network characteristics.
3. ***Land use models*** generally are mathematical tools that forecast demographic and economic measures of land-based activities. These measures can be described as meaningful attributes of the population (e.g., age-group cohorts, income, jobs, and so forth), but also can be expressed in terms of development (e.g., residential dwelling units, commercial floor space, and so forth). They take into account trends and policies regarding demographic and economic development, as well as the supply of developable land. The shape of the transportation network and its possible influence on the location of human activities are taken into account, but usually in a generalized manner. Market forces (the timing, magnitude and location of development) also are considered but again usually on a broad, often qualitative scale. Among other uses, the results serve as input to a travel demand forecasting model. However, generally there is little or no feedback from travel demand forecasting models into land use models.
4. ***Integrated land use-transportation (urban) models*** simulate the interaction of land use and transportation. They are intended to provide a feedback mechanism between land use models and travel demand forecasting models. For example, a new or improved transportation link can influence the timing, type, and extent of development in a particular area, which in turn can influence the need for further network improvements. Similarly, the evolution of land-based human activities influences the demand for improved transportation services, which in turn further influences development. Therefore, integrated models take land use models a step further by also simulating the location of human activities as a function of transportation accessibility. Similarly, integrated models do not simply provide land use input to travel demand forecasting models. Some integrated models focus on residential-employment allocation (i.e., the movement of people). Recent models provide a more generalized treatment of an area's economic and demographic activities (i.e., the movement of people and goods).
5. ***Transit accessibility*** describes how well a given point in an urban area is connected by transit to other points within the area. Accessibility can be defined in many ways:
   - As the absolute existence of a physical means of traveling between two points, where no other link exists (in this case, by transit);
   - As the relative level of service (e.g., speed, cost, comfort, and so forth) of a particular transit link, where alternate transit links exist and which may offer different levels of service; and
   - As the relative level of service of a particular transit link, compared with alternate modes (e.g., auto) which provide the same link.
6. ***Four-stage process*** refers to the commonly used travel demand forecasting paradigm. The four stages are as follows:

- *Trip generation*, in which the trips generated by the individual "zones" of a metropolitan region are calculated. The calculation relates the trips produced by and attracted to each zone as a function of the land use in that zone. Here, "land use" serves as a proxy for human activities (e.g., dwelling units, employment, and so forth). Trips commonly are generated according to the purpose of the trip and, less commonly, according to the mode. Because the household (i.e., the dwelling unit) is the basis for many trip-making characteristics, the trip generation functions can differentiate according to key household attributes: notably, household size, automobile availability and dwelling unit type.
- *Trip distribution*, in which the generated zonal trips for the different purposes are distributed among the different zones. The distribution takes into account the different types of land uses in each zone and their relative magnitude. The commonly used "gravity" formulation also takes into account the relative impedance among zones, where impedance is a measure of the relative accessibility of each zonal pair. That is, impedance is a function of the region's transportation network and can take into account the zone-to-zone travel times and travel costs (e.g., transit fares, tolls, parking charges, and so forth).
- *Mode split* takes the distributed trips by purpose and allocates these among the different available modes. A common choice is between the private automobile and public transit. However, mode split models also can differentiate between automobile driver and automobile passenger, as well as between submodes of public transit (e.g., heavy rail, light rail, surface bus, and so forth). Some models can differentiate among high-occupancy vehicle categories, as well as non-motorized modes (e.g., walking and bicycling). Mode choice commonly is made as a function of modal attributes; notably, relative zone-to-zone travel times and out-of-pocket costs, but also can account for comfort, convenience, the need to transfer, and so forth.
- *Trip assignment* "loads" the trips for each mode onto the respective transportation networks. This translates the zone-to-zone trips by mode (for all purposes) into specific automobile volumes on each road section (link), transit ridership on each segment of a bus route, and so forth. The assignment is commonly based on zone-to-zone travel time and out-of-pocket cost. Some assignment algorithms also can account for the dynamic effects of congestion on the choice of route.

The reader is cautioned again that this description has been deliberately simplified. Readers should be aware that there are numerous variations and refinements to the process described above. Various techniques and approaches exist for each of the four stages. Numerous transportation planning and modeling textbooks offer more exhaustive treatments.

Some specific technical terms are referenced in the discussion of the modeling classification system (Section 5.2). The most important of these, related to travel demand forecasting models, are reviewed below:

7. ***Activity-based methods*** is an emerging approach to travel demand forecasting. Very simplistically, the approach recognizes that a person's daily trips are made as part of a chain of activities. This chain affects the choices that each traveler must make: when a trip should be made, by what mode, by what route, the sequence of trips (e.g., go to the store on the way to work or on the way home), and so forth. In contrast, the traditional four-stage process is a trip-based approach, which generally treats these decisions only as sequential, if not unrelated, events.
8. ***Aggregate/disaggregate analysis*** describes the level of detail at which an analysis occurs. The traditional four-stage process relies on traffic analysis zones (analogous to census tracts). Thus, all travel activity and all land use characteristics are "aggregated" to zonal totals (e.g., 153 dwelling units and 80 jobs in zone x generate 43 trips by automobile and 13 trips by public transit during the AM peak hour). However, such aggregations often mask essential differences within the zone that are critical to the determination of travel characteristics (e.g., the type of job, the type of household, household size, and so forth). Therefore, newer approaches (e.g., activity-based methods) use disaggregate bases—an approach made possible in part by the growing availability of GIS data bases that can support the appropriate level of detail.
9. ***Logit/non-logit mode split*** divides mode choice models into two broad classes. To some extent, these classes reflect the difference between the disaggregate and aggregate treatments, respectively. Very broadly, the logit formulation describes (mathematically) how an individual traveler makes decisions, in order to maximize his or her "utility" (e.g., for out-of-pocket cost, door-to-door travel times, need to transfer, waiting time at the bus stop, personal security, comfort, and so forth) as a function of how he or she values these individual attributes relative to the others. This disaggregate approach is in contrast to the use of simplified factors (among other methods). Often, these are applied to all trips between two zones (or at even greater aggregations), with little or no accounting for variations among the demographic or socioeconomic characteristics within zones.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually draw on approximately 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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